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Representations of stratocumulus cloud regimes in climate models and emergent constraints in the radiative responses to future warming

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Model's cloud regimes have many biases

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Tsushima et al.,(2012) found followings in CMIP5 models

- Low clouds is less frequent and too bright (Williams and Webb 2009, Nam et al. 2012)
- Mid level cloud is less frequent
- Frontal regime is more frequent and less bright
- Anvil/Cirrus regimes are too few

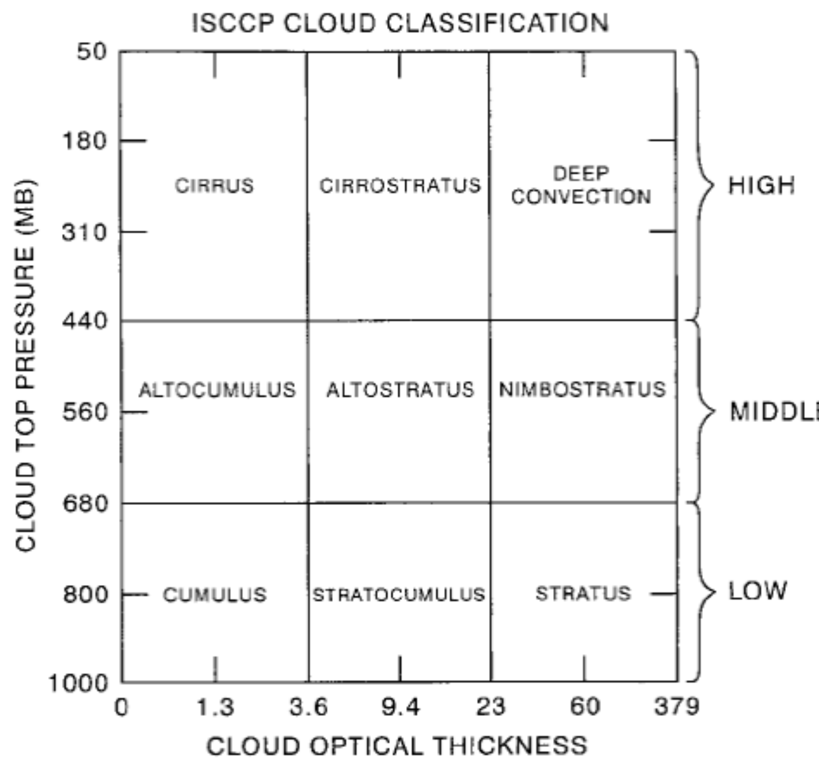
Attempt to constrain the uncertainty in cloud feedback in climate models by taking into account the bias in control climate simulation. Williams and Tselioudis, 2007(WT07), Williams and Webb, 2009 (WW09)

Question: Does the underestimate/overestimate of any property of a cloud regime in models relate to the magnitude of cloud feedback?

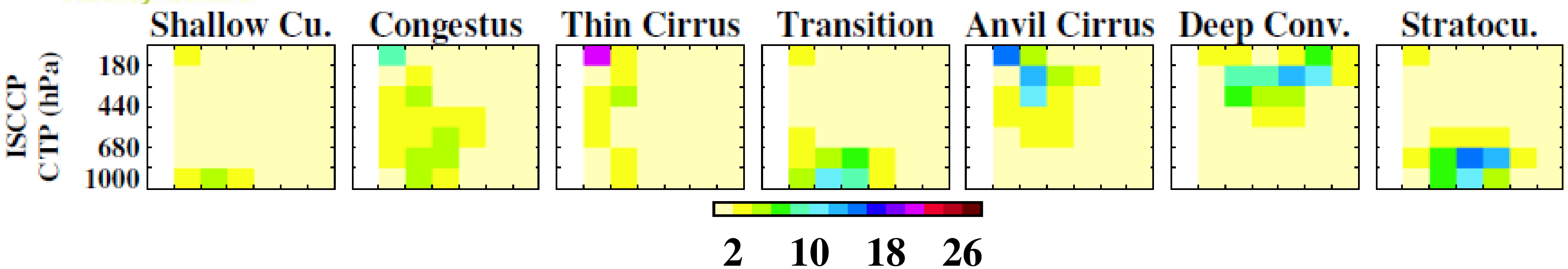
- In the seasonal variation, underestimate / overestimate of CRE of a regime in a model does not leads to an underestimate / overestimate of the magnitude of its seasonal variation, except anvil/cirrus regime. (Tsushima et al.,2012)
- How about in the global warming?
- In this talk, a study by Tsushima et al.,(2015) are presented.

The ISCCP data (Rossow and Shiffer, 1991) and the ISCCP simulator (Webb et al.,2001)

- ISCCP data (July1983 -)



Cloud regime analysis based on Williams and Webb (2009) clustering method



Cloud Regime Projection Methodology

- Reference in-cloud mean albedo(α), cloud top pressure (CTP), total cloud cover (TCC) for each regime from Williams and Webb (2009).
- In GCM, (α, CTP, TCC) is calculated using the ISCCP-simulator. This is assigned to the closest , (α, CTP, TCC) of the observed regime, using a normalised minimum root-sum-square measure of distance.

Data and analysis method

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Observations

- Daily Data:
- Radiative fluxes: CERES SYN1deg, ERBE, ISCCP-FD
- For clear-sky longwave, use ERA-interim
- Clouds: ISCCP total cloud cover (TCC), in-cloud mean albedo(α), cloud top pressure (CTP), from ISCCP D1

Models

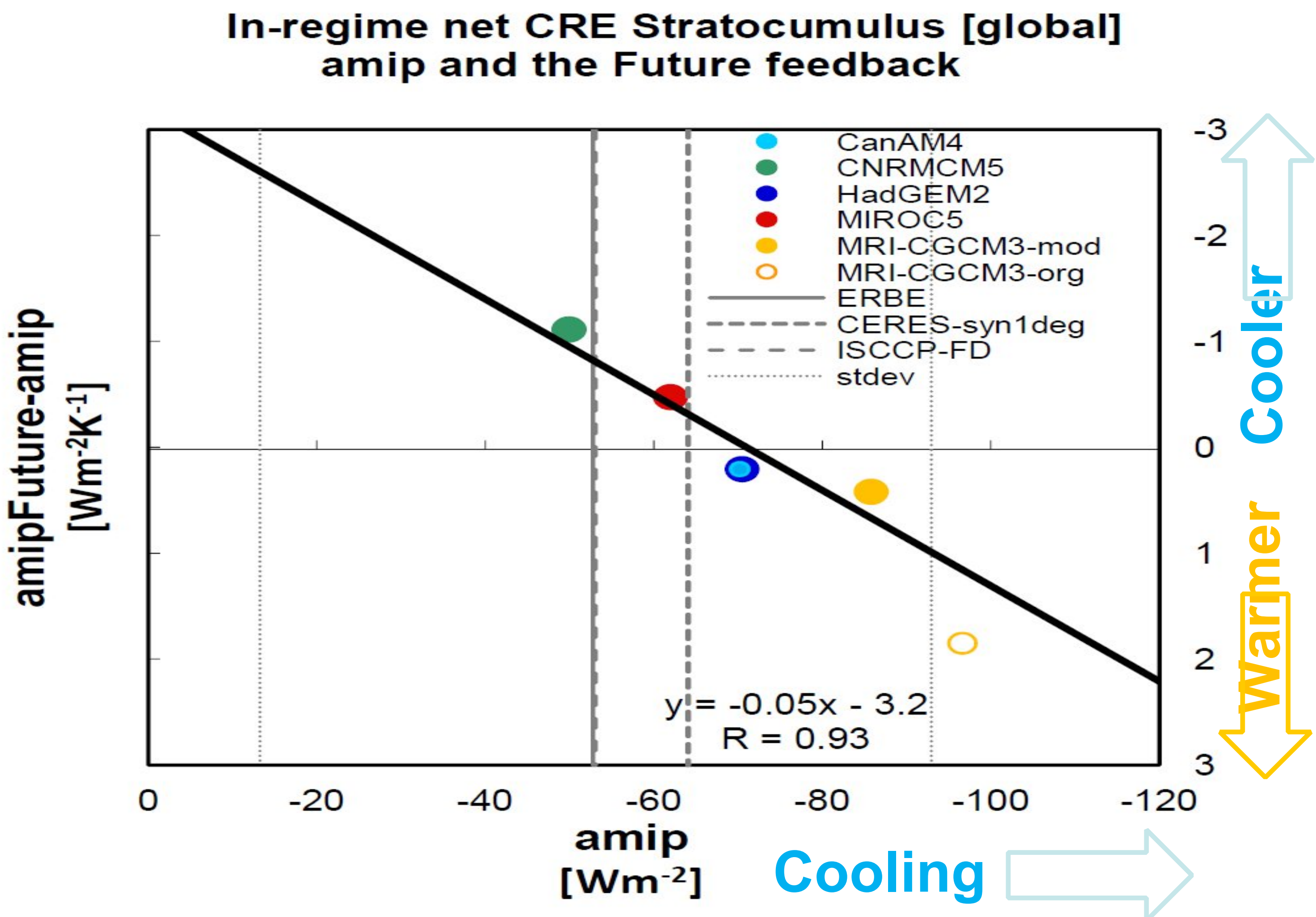
- 5 models from CMIP5 (HadGEM2-A, CanAM4, CNRM-CM5, MIROC5, MRI-CGCM3, MRI-CGCM3-bugfixed)
- Experiment: CMIP5 amip run & amipFuture run (hereafter 'Future') 30yrs (1979-2008) of each run
- Radiative fluxes, ISCCP-simulator outputs equivalent to observational ISCCP data and other variables are analyzed

Cloud Regime Analysis Methodology

- Cloud radiative effects (CREs), relative frequency of occurrence (RFO) and in-regime CREs in amip run and the difference are analyzed.
- For each variable, the correlation between the control climate and the changes in Future climate is calculated.

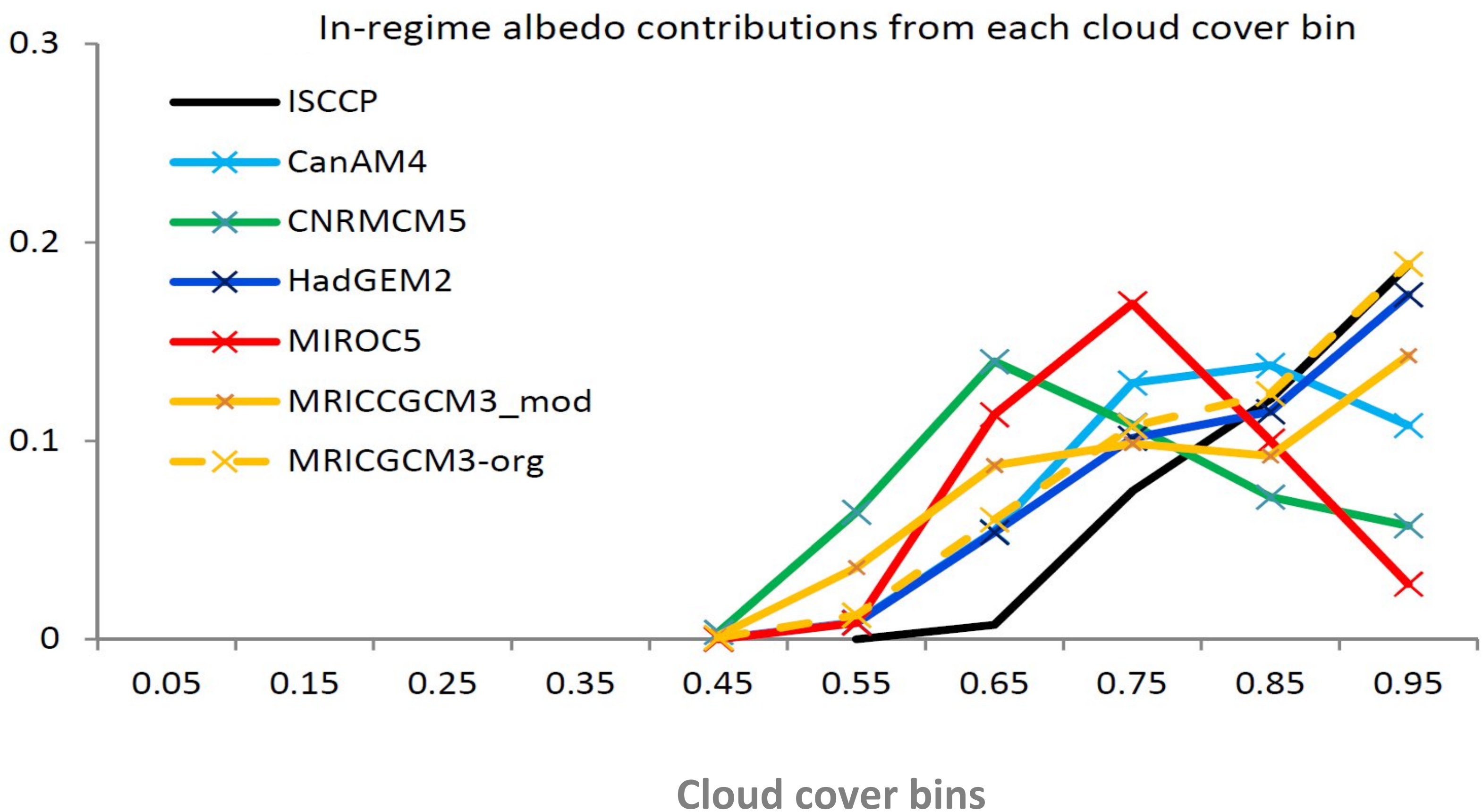
- No correlation is found for either present-future RFO or net CRE for all regimes.
- No correlation is found for in-regime net CRE for all regimes except one: **stratocumulus regime**

A correlation in a radiative effect and the feedback



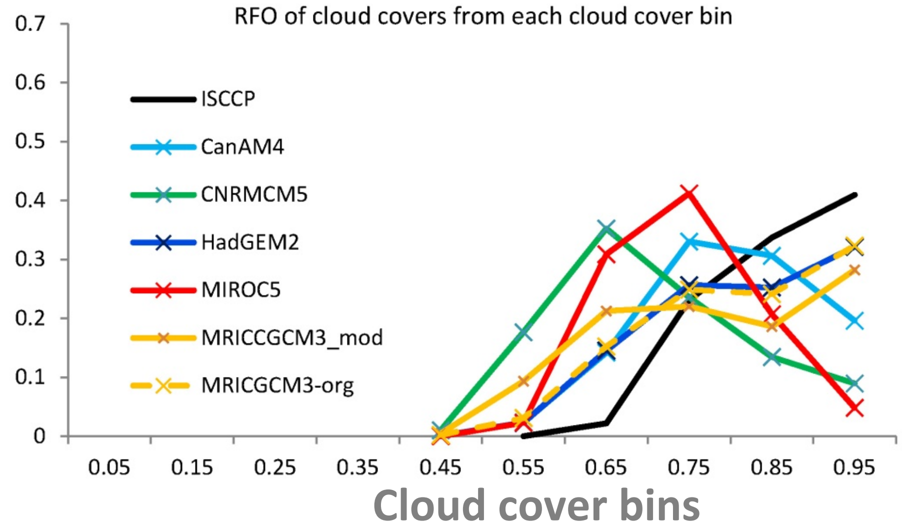
Albedo within the stratocumulus regime drives the correlation in the net CRE and the bias.
What is responsible for this bias?

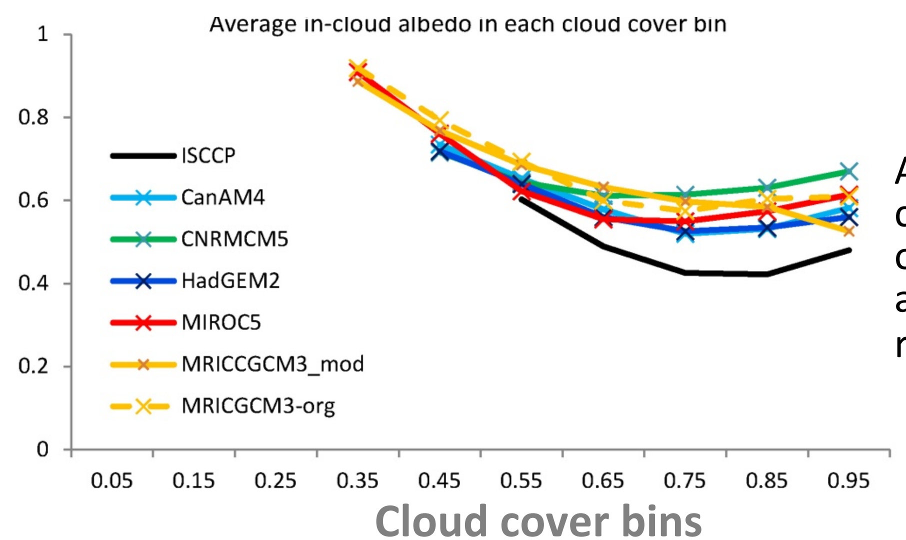
Different cloud cover bins' contributions to the tropical [20°S, 20°N] stratocumulus regime's in-regime albedo (amip)



- Models systematically underestimate contributions from overcast cloud cover bins are underestimated but overestimate those from broken cloud cover bins. The overestimate in broken clouds are responsible for the in-regime albedo bias.

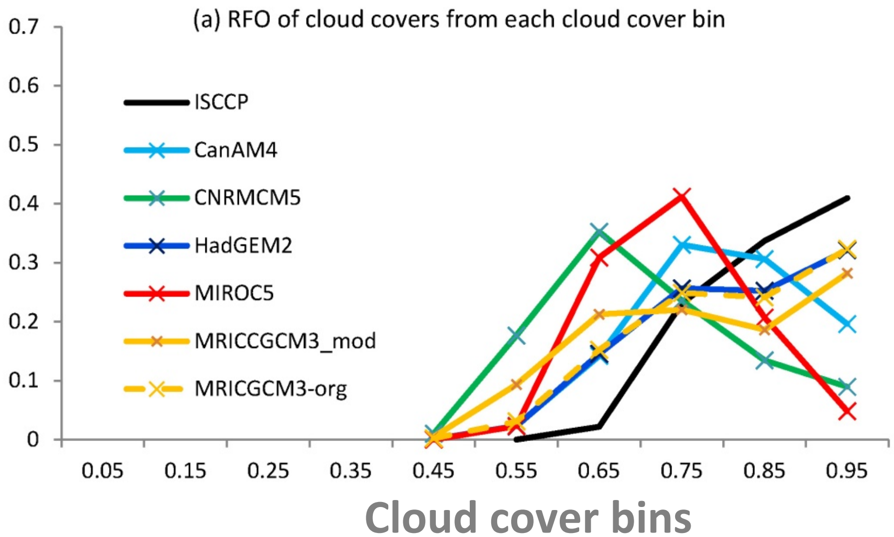
‘Better’ bulk property out of compensating errors

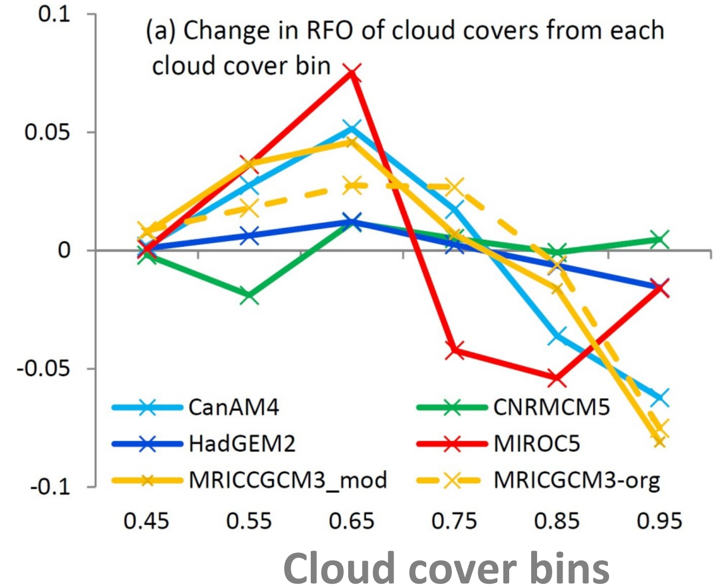


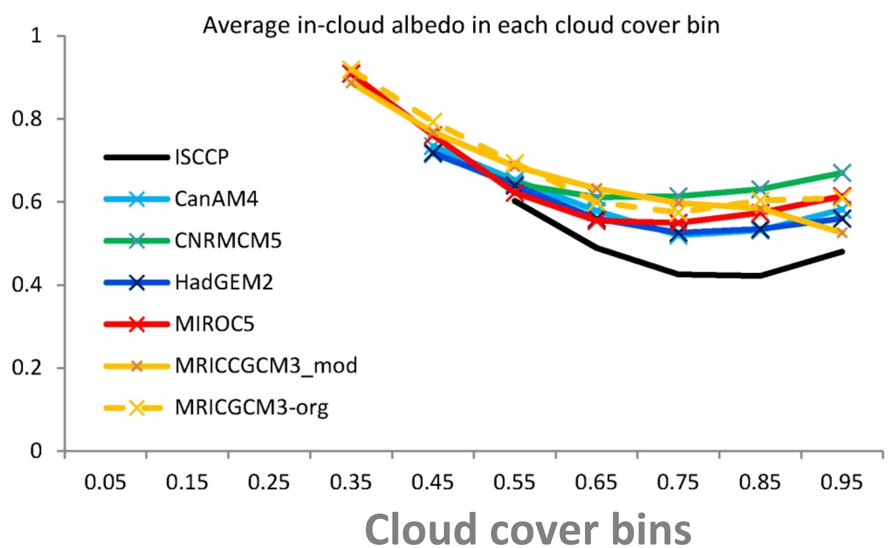


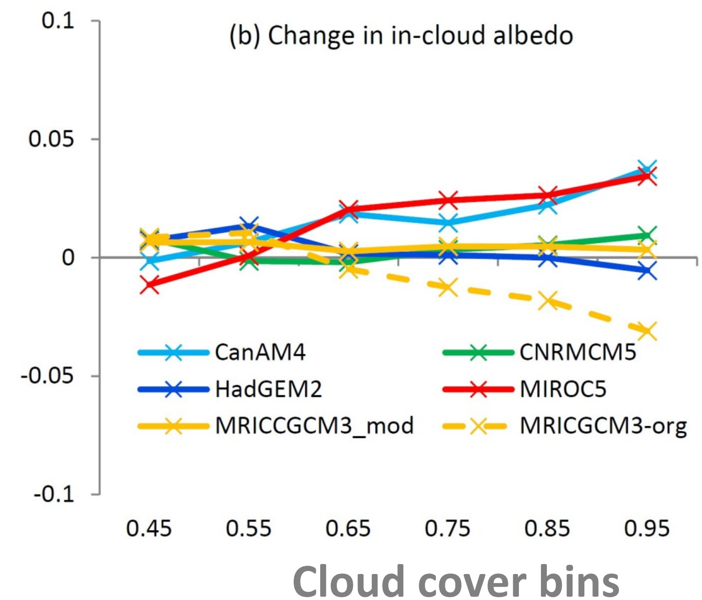
Although the overestimate of in-cloud albedo contributes to models’ overestimate of the in-regime albedo to some extent, RFO is responsible for the bias.

There is no obvious correlation in distributions of in-cloud properties between control climate and future response

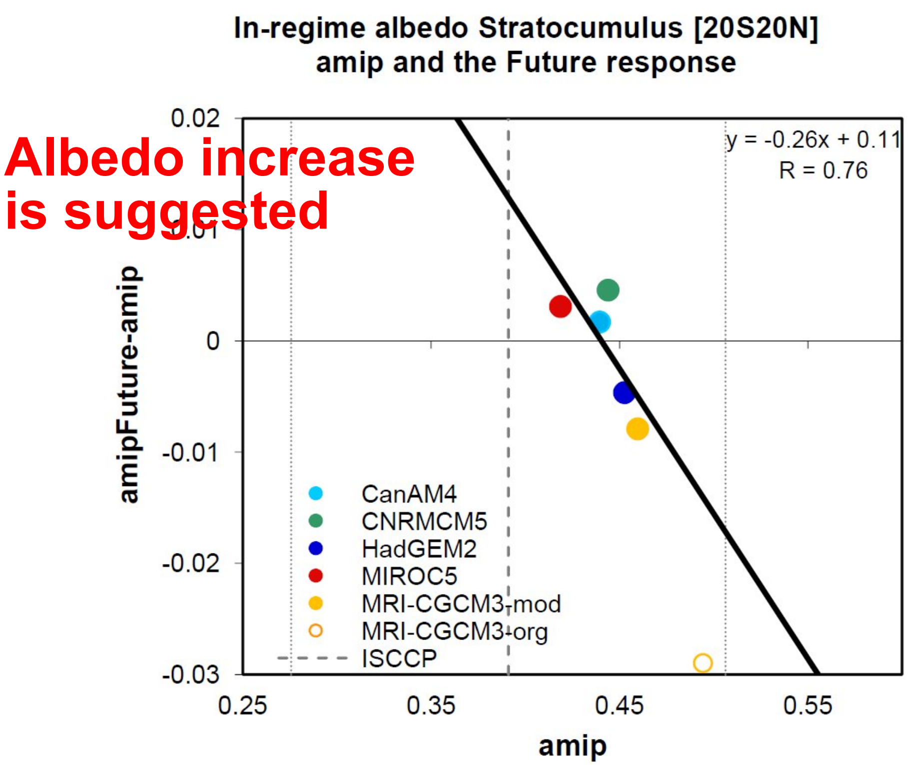


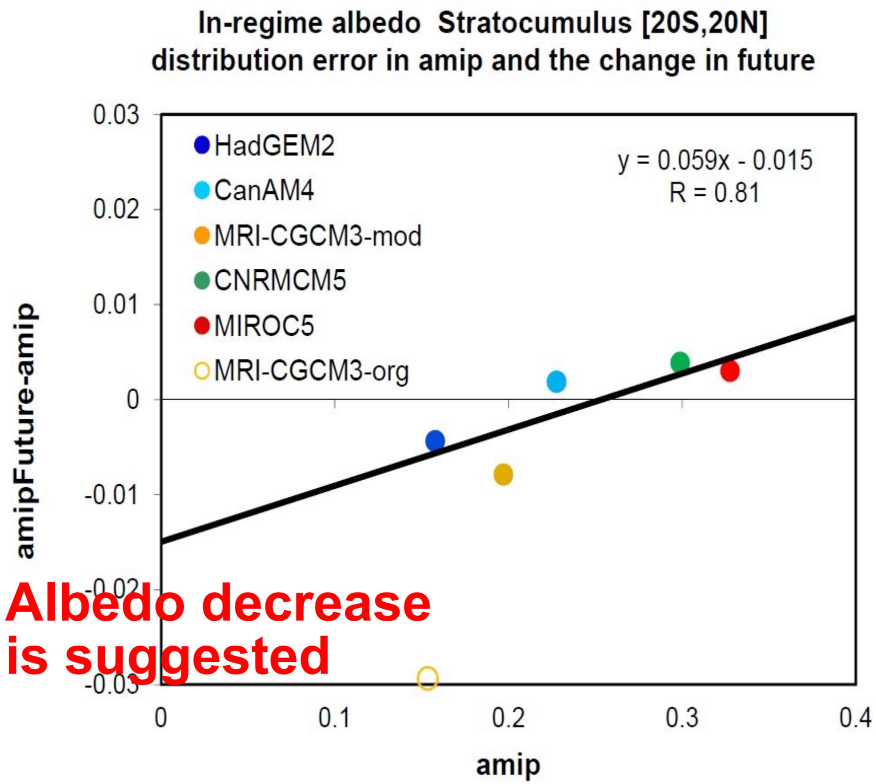






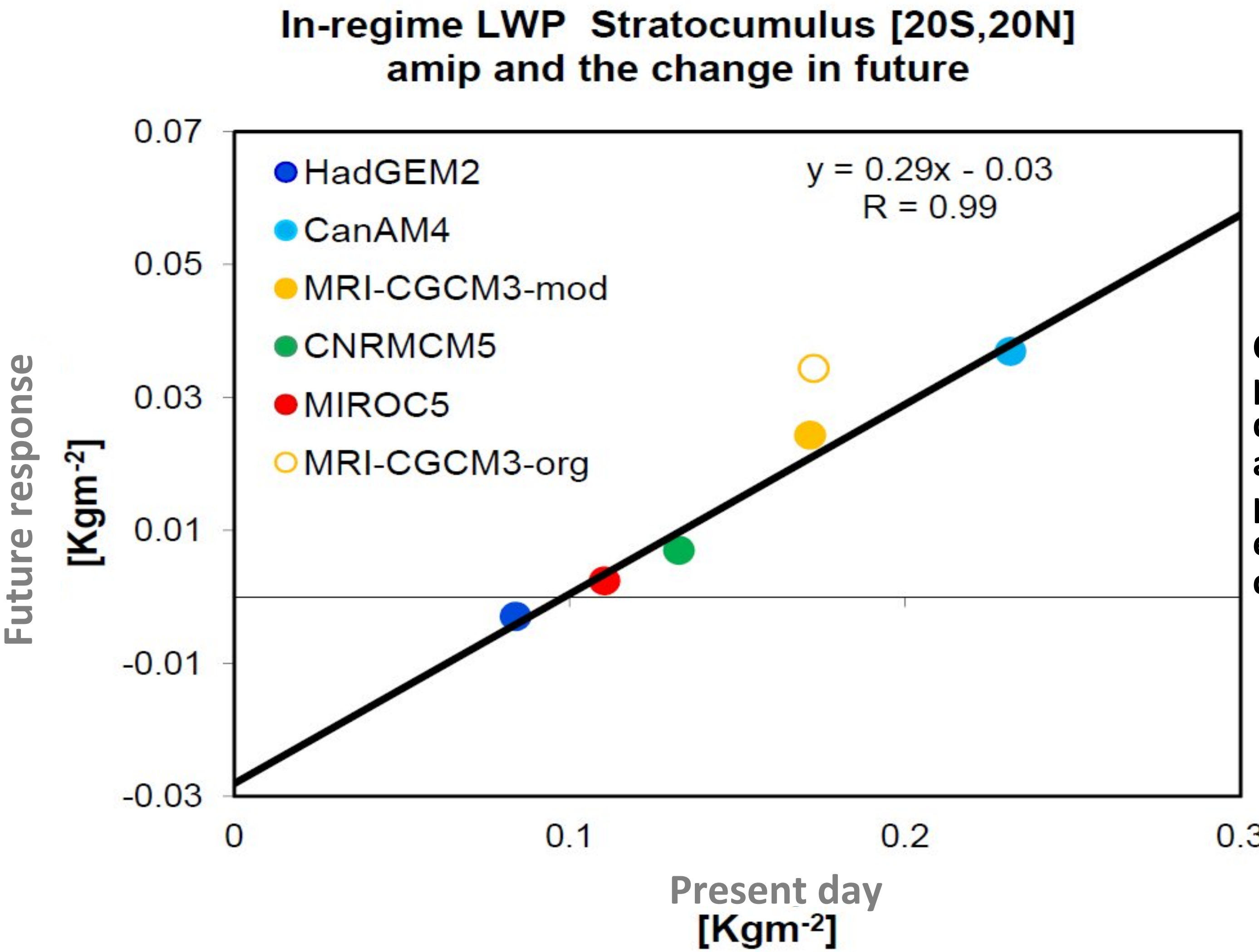
Which observational constraint should we use?





Breakdown analysis of a bulk property into physical properties is necessary to better understand the behavior of the cloud regime.

There is a strong positive correlation between the in-regime liquid water path in the control climate and its response to warming.



Cloud water is a physical property and is independent of a model's radiative assumptions, and it could potentially provide a useful emergent constraint on cloud feedback.

Summary

- Future responses of cloud regimes are analyzed for five CMIP5 models and correlations between the control climate performance and future responses in different models are investigated.
- A correlation is found in stratocumulus regime for the net cloud radiative effect (CRE) within the regime, which is driven by the albedo within the regime (in-regime albedo).
- All models overestimate the in-regime albedo. The bias is firstly from relatively too frequent broken cases, secondary from a systematic overestimate of the in-cloud albedo.
- The relative frequency of overcast cases (broken clouds) tends to decrease (increase), which suggests that cloud cover distribution feedback is positive in the in-regime albedo feedback.
- The future response of in-cloud LWP of the stratocumulus regime is positively correlated to that in the control climate. Observations the LWP could give constraint to the feedback.
- Breakdown analysis of a bulk property into physical properties is necessary to better understand the behavior of the cloud regime.